Vikram A Sarabhai Community Science Centre (VASCSC) is a pioneering institution working in the field of science education, founded by Dr. Vikram Sarabhai in 1966. Its mandate is to stimulate interest, encourage and expose the principles of science and scientific method in the community and also to improve and innovate various areas of science education. VASCSC has well-equipped laboratories in Biology, Chemistry, Physics, Computers, Electronics, Mathematics and Model Rocketry as well as a Workshop, Library and Innovation Hub.

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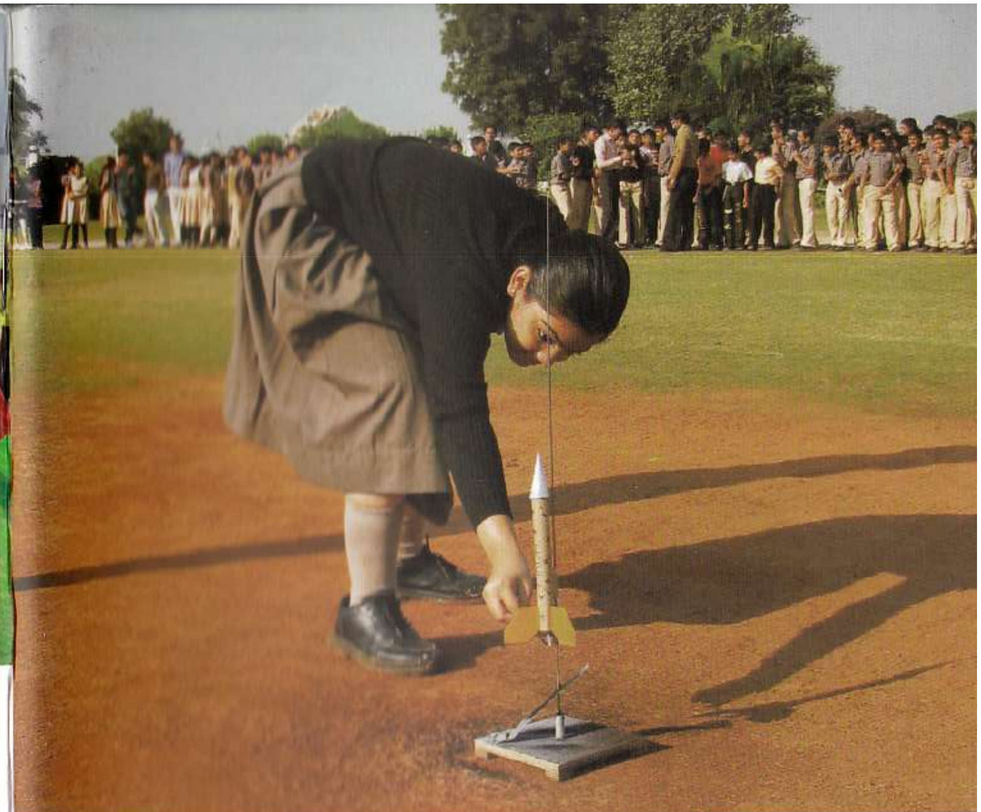

MODEL ROCKETRY

STUDENT HANDBOOK

Single Stage Solid Propellant Model Rockets

VIKRAM A SARABHAI
COMMUNITY SCIENCE CENTRE

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STUDENT HANDBOOK

Single Stage Solid Propellant Model Rockets

DEVELOPED BY
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PREFACE

The thrill and adventure of space exploration has not left many untouched. The success of space programmes has attracted the attention of many, especially young people, who desire to build rockets on their own. However, rocket fabrication requires training and a lot of care. Model Rocketry is an activity which allows these young enthusiasts to fulfil their interest. Some years back, no facility, guidance or material was available for those wanting to pursue Model Rocketry. This led to the initiation of the 'Model Rocketry Lab' at Vikram A Sarabhai Community Science Centre (VASCSC). This activity was inspired by late Dr. Howard Galloway from USA, when he was working for the SITE project of Indian Space Research Organization (ISRO), Ahmedabad. Various training programs for teachers and students were offered every year in Model Rocketry.

Today, Model Rocketry is a popular activity of the Centre. Participants of this activity not only learn to build model rockets from easily available simple materials, but are also encouraged to experiment with their designs and come up with new ideas in rocket fabrication. This manual is a guide and will supplement the Model Rocketry kit. The users will be able to fabricate water booster model rockets using this manual. They will also be able to experiment with the parts of model rockets and use their own imagination to construct them. Different aspects of model rocketry are covered in the chapters of this manual. VASCSC proposes to enhance its model rocketry activity, formulate a space education programme, and carry it to a large number of schools in the country. I hope the users will find it useful and in the future too, the Centre will be able to bring out such manuals for different categories of model rockets and nurture the enthusiasm of budding model rocketeers.

Dilip Surkar
Executive Director

INDEX

1. INTRODUCTION

1.1 Historical Overview

The invention of first true rockets was accidental. In the first century A.D., the Chinese reportedly had a simple form of gunpowder made up of saltpetre, sulphur and charcoal dust. They used this kind of gunpowder mostly for fireworks in the religious and other festive celebrations. To create explosions, they filled bamboo tubes with gunpowder and tossed them into fires. Some of those tubes failed to explode and instead skittered out of the fires, propelled by the gases and sparks produced from the burning gunpowder.

The Chinese began experimenting with gunpowder-filled tubes. At some point, they attached bamboo tubes to arrows and launched them with bows. Soon they discovered that these gunpowder tubes could launch themselves just by the power produced from the exhausting gases. The true rocket was then born.

The date reporting the first use of true rockets was in 1232 A.D. At this time, the Chinese and Mongols were at war with each other. During the battle of Kai-Keng, the Chinese repelled the Mongol invaders by a barrage of arrows of flying fire. These fire-arrows were a simple form of solid-propellant rockets. A tube, capped at one end, contained gunpowder. The other end was left open and the tube was attached to a long stick. When the powder ignited, the rapid burning of powder produced fire, smoke and gas that escaped out of the open end and produced a thrust. The stick acted as a simple guidance system that the rocket headed in one general direction as it flew through the air. How effective these arrows of flying fire were as weapons of destruction is not clear, but their psychological effects on the Mongols must have been formidable!

Following the battle of Kai-Keng, the Mongols produced rockets of their own and may have been responsible for the spread of rockets to Europe. By the 16th century, rockets fell into a time of disuse as weapons of war, though they were still used for fireworks displays. A German fireworks maker, Johann Schmidlap, invented the step rocket, a multi-staged vehicle for lifting fireworks to higher altitudes. A large sky rocket (first stage) carried a smaller sky rocket (second stage). When the large rocket burned

out, the smaller one continued to a higher altitude showering the sky with glowing cinders. Schmidlap's idea is basic to all rockets today that go into outer space.

Rockets in India

Chinese traders used to visit South Indian port of Quilon (now renamed as Kollam) and Arab traders used to visit northern Malabar region of Kerala especially for white pepper trade, and through them gunpowder might have reached India. The earliest known use of gunpowder in India was recorded in 1176-77 A.D. During this period, Benjamin of Tudela, Spain, visited Quilon and observed people worshiping the Sun. To symbolise the Sun they used Sun-Disc which rotated with a thunderous noise throwing fire sparks which indicated use of gunpowder.

After 1400 A.D., there are many references in Sanskrit literature, such as Agnichurna (gunpowder), Agnibana (rocket) and Agnikrida (fire works), for the use of gunpowder. Fire crackers known as chinna-bedi and chinna-padakkam were familiar words in the Malayalam literature which has several references to crackers. In 15th century various kinds of fireworks were displayed at Vijayanagar Kingdom during festivals.

The Mysore State further developed the gunpowder for rockets by using iron cylinders. This change produced increased bursting pressure and also allowed the gunpowder to be packed densely which resulted in greater thrust and range. These rockets had a range of about 1000 yards. It was effectively used against the British.

▸ 1.2 Rocketry and Science

During the later part of 17th century, the great English physicist Sir Isaac Newton (1642-1727) laid the scientific foundation of modern rocketry. Newton organised his understanding of physical motion into three laws. These laws perfectly explain the motion of the rockets as well as working of the rockets in some specific medium and in vacuum. Newton's laws of motion gave a practical impact on design of rockets. In 1720, a Dutch professor, Willem Gravesande, built model cars propelled by steam jets. Rocket experimenters in Germany and Russia began working with rockets of mass more than 45 kg. Some of these rockets were so powerful

that their escaping exhaust flames bored deep holes in the ground even before lift-off.

During the end of the 18th century and early into 19th century, rockets experienced a brief revival as a war-weapon. The success of Indian rocket barrages against the British in 1792 and again in 1799 caught the interest of Colonel William Congreve. He set out to design rockets for use by the British military. His rockets, the Congreve rockets, were very successful in battle. Even with his work, the accuracy of rockets had not much improved from early days. The devastating nature of war rockets was not their accuracy or power; but their numbers. All over the world, rocket researchers experimented with ways to improve the accuracy of the rockets. An Englishman, William Hale developed a technique called spin stabilization. In this method, the escaping exhaust gases struck small vanes at the bottom of the rocket, causing it to spin much as a bullet does in flight. Many rockets still use variations of this principle today. Rocket use continued to be successful in battles all over the European continent.

▸ 1.3 Beginning of Modern Rocketry

In 1898, a Russian school teacher, Konstantin Tsiolkovsky (1857-1935) proposed an idea of space exploration by rocket. In a report published by him in 1903, he suggested the use of liquid propellants for rockets in order to achieve better performance. He stated that only exhaust velocity of escaping gases limited the speed and range of rockets. For his ideas, careful research and great vision, Tsiolkovsky has been called the 'Father of Modern Astronautics'.

Early in the 20th century, an American, Robert H. Goddard (1882-1945), conducted practical experiments in rocketry. He became interested in different ways of achieving higher altitudes than lighter-than-air balloons. He published a pamphlet in 1919 entitled 'A Method of Reaching Extreme Altitudes'. Today this mathematical analysis is very well applicable to meteorological sounding rockets. In the pamphlet, he reached several conclusions important to rocketry. From his tests, he stated that a rocket operates with greater efficiency in a vacuum than in air.

At the time, most people mistakenly believed that the presence of air was necessary for a rocket to push against. He also stated that multistage of step rockets were the answer to achieving high altitudes and that the velocity needed to escape Earth's gravity could be achieved in this way. His earliest experiments were with solid-propellant rockets. In 1915, he began to experiment with various types of solid fuels and to measure the exhaust velocities of burning gases. While working on solid-propellant rockets, he became convinced that a rocket could be propelled better by liquid fuel. No one had ever built a successful liquid-propellant rocket before. It was a much more difficult task than building solid-propellant rockets.

For liquid propellant rockets, fuel and oxygen tanks, turbines and combustion chambers would be needed. In spite of the difficulties, Goddard achieved the first successful flight with a liquid-propellant rocket on March 16, 1926. Fuelled by liquid oxygen and gasoline, the rocket flew for only two and a half seconds, climbed 12.5 metres and landed 56 metres away in a cabbage patch. By today's standards, the flight was unimpressive, but like the first powered airplane flight by Wright Brothers in 1903, Goddard's gasoline rocket became the forerunner of a whole new era in rocket flight. Goddard's experiments in liquid-propellant rockets continued for many years. His rockets grew bigger and flew higher. He developed a gyroscope system for flight control and a payload compartment for scientific instruments. Parachute recovery systems returned the rockets and instruments safely to the ground. We call Goddard the 'Father of Modern Rocketry' for his achievements.

▸ 1.4 Model Rocketry: An Educational Tool

With model rocketry, one can illustrate 'Space Age' principles with effectiveness and at the same time give the student a chance to explore related fields. As a result of their unlimited possibilities, they can also be used in many educational situations. Launching, tracking, time measuring and recovery of the rocket provide an excellent opportunity for the students to experience success and develop a sense of pride in their accomplishment and apply some mathematics they have been studying. Concepts such as distance, velocity, acceleration, momentum, Newton's laws of motion and gravitation, aerodynamic forces like thrust, drag, lift

and gravity, Bernoulli's principle, the elements of propulsion, etc. are easier to comprehend when they get involved in this activity. Apart from enjoying the work, the children learn several aspects of rocket launching, projectile motion, thrust mechanism and stability in an informal manner. The students can fabricate model rockets using inexpensive material like thick paper, adhesive and motors of firecracker rockets. These rockets are preferred because they are harmless. Children can learn various aspects of designing the model rockets, the importance of fins, nose cone, stability, launching mechanism, etc. After achieving a certain degree of proficiency at constructing simple single stage model rockets, children may proceed to build double stage, triple stage, parachute and streamer rockets using firecracker rockets and water booster rockets. Developed countries like United states, Canada, Australia, etc. have been much involved in the organization, promotion, development, education and advancement of amateur aerospace activities, particularly Model Rocketry.

▸ 1.5 What is a Model Rocket?

A model rocket is a real, flying, small size model of an actual big scientific or military type rocket or missile. The main feature of the model rocket is that it is constructed from non-metallic, light weight materials. The motors used are non-metallic, self-contained solid propellant motors which are ignited either by incense sticks or electrically. Thus, these model rockets are safe, challenging, educational rockets for school-college students and lay public.

There are different categories of model rockets: One is solid propellant model rockets and other is water boosters. Water Booster Model Rockets propel with water and air as fuel. In solid propellant model rockets, there are different types such as Single Stage, Double Stage, Triple Stage, Parachute, Streamer, Clustered-motored, etc. Single Stage Model Rockets are the simplest type of rockets. However, these types of rockets have one fundamental feature in common that all of them work based on the Newton's three laws of motion. The third law of motion states; "Any action on a body is counteracted with equal and opposite reaction." This opposite reaction is responsible for propelling the rocket upward, overcoming the Earth's gravitational force and the rocket's own weight.

▸ 2.1 Newton's Laws of Motion

All the rocket motors operate under three basic rules. These rules are commonly known as Newton's laws of motion. These rules were given by the English Physicist Sir Isaac Newton in 1687. To put it simply, the first law states that: "Objects at rest will stay at rest and objects in motion will continue the state of motion in a straight line unless acted upon by an unbalanced external force." The second law states that: "Force is equal to mass times acceleration". The third law states that: "For every action there is always an opposite and equal reaction". All these three laws help us understand how things really move. But using them, precise determinations of rocket performance can be made.

▸ 2.2 Newton's First Law of Motion

The statement of the first law is very obvious, but to know its meaning in a real sense it is very necessary to understand the meaning of physical terms: rest, motion and unbalanced force. Rest and motion can be thought of as being opposite to each other. Rest is the state of an object when it is not changing its position with respect to its surroundings. If you are sitting in a still chair, you can be said to be at rest. This term, however, is totally relative. The chair may actually be one of many seats on a speeding airplane. The important thing here to remember is that you are not moving with respect to your immediate surroundings. If rest were defined as a total absence of motion, it would not exist in nature. Even if you were sitting in your chair at home, you would still be moving, because your chair is actually sitting on the surface of a spinning planet (the Earth) that is orbiting a star (the Sun). The star is moving through a rotating galaxy (the Milky Way) that is, itself moving through the Universe. While sitting still, you are in fact, travelling at a speed of hundreds of kilometres per second. Motion is also a relative term.

A rocket blasting off the launch pad changes from a state of rest to a state of motion. The third important term to understand is unbalanced force. If you hold a ball in your hand and keep it still, the ball is at rest. All the time the ball is held there though, it is being acted upon by forces. The force of gravity is trying to pull the ball downward, while at the same time your

hand is pushing against the ball to hold it up. The forces acting on the ball are balanced. Let the ball go, or move your hand upward, the forces become unbalanced. The ball then changes from a state of rest to a state of motion.

In rocket flight, forces become balanced and unbalanced all the time. A rocket on the launch pad is balanced. The surface of the pad pushes the rocket up while gravity tries to pull it down. As the motors are ignited, the thrust from the rocket unbalances the forces, and the rocket travels upward. Later, when the fuel inside the rocket is completely exhausted, it slows down, stops momentarily at the highest point of its flight, and then falls back to the Earth.

▸ 2.3 Newton's Third Law of Motion

For the time being, we will skip the second law and go directly to the third. This law states that every action has an equal and opposite reaction. If you have ever stepped off a small boat that has not been properly tied to a pier, you will know exactly what this law means. A rocket can lift off from a launch pad only when it expels gas out of its motor. The rocket pushes on the gas, and the gas in turn pushes on the rocket.

In rockets, the action is the expelling gas out of the motor. The reaction is the movement of the rocket in the opposite direction. To enable a rocket to lift off from the launch pad, the action or thrust from the motor must be greater than the weight of the rocket. While on the pad, the weight of the rocket is balanced by the force of the ground pushing against it. Small amounts of thrust result in less force required by the ground to keep the rocket in balance. Only when the thrust is greater than the weight of the rocket does the force become unbalanced and the rocket lifts off. In space, where unbalanced force is used to maintain the orbit, even tiny thrusts will cause a change in the unbalanced force which results change of speed or direction of the rocket.

One of the most commonly asked questions about rockets is how they can work in space, where there is no air for them to push against. The answer to this question can be given from the third law. Imagine the skateboard

again. On the ground, the only part air plays in the motions of the rider and the skateboard is to slow them down. Moving through the air causes friction which is known as a drag. The surrounding air impedes the action-reaction. As a result, rockets actually work better in space than they do in air. As the exhaust gas leaves the rocket motor, it must push away the surrounding air; this uses up some of the energy of the rocket. In space, the exhaust gases can escape freely.

▸ 2.4 Newton's Second Law of Motion

This law of motion is essentially a statement of a mathematical equation. The three terms of the equation are mass (m), acceleration (a), and force (F). The equation can be written as,

$$F = ma$$

To explain this law, we will use the example of cannon. When the cannon is fired, an explosion propels a cannon ball out of the open end of the barrel. It flies to its target. At the same time the cannon itself is pushed backward. This is action and reaction at work (Third law). The force acting on the cannon and the ball is the same. What happens to the cannon and the ball is determined by the second law.

$$F = m\,(\text{cannon}) \times a\,(\text{cannon})$$
$$F = m\,(\text{ball}) \times a\,(\text{ball})$$

The first equation refers to the cannon and the second to the cannon ball. In the first equation, the mass is of the cannon itself and the acceleration is the movement of the cannon. In the second equation, the mass is of the cannon ball and the acceleration is its movement. Since the force (exploding gunpowder) is the same for the two equations, it can be represented as follows:

$$m\,(\text{cannon}) \times a\,(\text{cannon}) = m\,(\text{ball}) \times a\,(\text{ball})$$

In order to keep two sides of equations equal, the acceleration varies with mass. In other words, the cannon have a large mass and a small acceleration, while the cannon ball has a small mass and a large acceleration.

Apply this principle to understand the motion of the rocket. Replace the mass of the cannon ball with the mass of the gases being ejected out of the rocket motor. Replace the mass of the cannon with the mass of the

rocket moving in other direction. Force is the pressure created by the controlled explosion taking place inside the rocket's motors. That pressure accelerates the gas one way and rocket, the other.

Some interesting things happen with rockets that do not happen with the cannon and ball in this example. With the cannon and cannon ball, the thrust lasts for just a moment. The thrust for the rocket continues as long as its motors are firing. Furthermore, the mass of the rocket changes during flight. Its mass is the sum of all its parts. Rocket's parts include: motors, propellant tanks, payload, control system and propellants. By far, the largest part of the rocket's mass is its propellants. However, that amount constantly changes as the motors fire. It means that rocket's mass gets smaller during flight. For the left hand side of the equation to remain in balance with right hand side, acceleration of the rocket has to increase as its mass decreases. That is why a rocket starts off moving slowly and goes faster and faster as it moves into space.

Newton's second law is especially useful while designing efficient rockets. To enable a rocket to climb into Low Earth Orbit (LEO), it is necessary to achieve a speed in excess of 7.78 km/s. A speed of over 11.2 km/s, called Escape Velocity, enables a rocket to leave the Earth and travel out into deep space. Attaining space flight speeds requires the rocket motor to achieve the greatest action force possible in the shortest time. In other words, the motor must burn a large mass of fuel and push the resulting gas out of the motor as rapidly as possible. Newton's second law can be restated as follows: "The greater the mass of rocket fuel burned and the faster the gas produced can escape the motor, the greater is the thrust of the rocket".

▸ 2.5 Momentum and Newton's Second Law of Motion

If an object is moving with uniform velocity, a force is required to change its speed and direction. This statement can easily be recognised by Newton's first law of motion. Linear Momentum (P) is defined by mass of the object (m) multiplied with its velocity(u) as given below

$$P = mu$$

From this equation, we can say that the object's momentum can be increased by either increasing mass or velocity. Non-relativistically, mass is

an invariant quantity for a given object; which means that momentum of the object can be changed by changing its velocity.

Changing an object's momentum is very important aspect in rocketry. The change in momentum means that over some period of time, either its mass is changed or its velocity is unchanged. The nozzle of the rocket motor, then, must be designed for a particular operating pressure range, such as vacuum conditions (as the space shuttle main engines) or for sea level conditions (as a model rocket motor). When the nozzle reaches its designed altitude operating pressure, the second term in the thrust equation drops off completely, and the thrust produced is equal to the momentum term:

$$F = \frac{dm}{dt \times v}$$

Here, we have made assumption that model rocket engines should be designed to operate at sea level atmospheric pressure conditions. This is not a bad assumption because for most of the model rocket motors, the entire burning occurs at low altitudes. These motors cannot be used for outer space. Under one of the assumptions we made, a model rocket motor should have a constant thrust over its entire burn period. However, as we all know, almost all motors available in market have a high initial lift-off thrust and then it levels off. This does not mean our equations are wrong, it means that the assumptions that we made were wrong. The mass flow of propellant can change over the duration of the rocket burn, but the thrust equation is still valid as long as we take very short periods of time where it can be assumed that Dt/dt = constant.

▸ 2.6 Considering Newton's Three Laws of Motion Together

If we consider three laws of motion together, we can get an idea about how rockets work. A force must be exerted for a rocket to lift off from a launch pad or for a craft in space to change speed or direction (First Law). The amount of thrust (force) produced by a rocket motor will be determined by the rate at which the mass of the rocket fuel burns and the speed of the gas escaping the rocket (Second Law). The reaction or motion of the rocket is equal to and in opposite direction of the action or thrust from the motor (Third Law).

3. BASIC STRUCTURE OF ROCKET

The first rockets ever built, the fire arrows of the Chinese, were not very reliable. Many just exploded on launching. Others flew on erratic courses and landed in the wrong place. Being a rocketeer in the days of the fire arrows must have been exciting, but also a highly dangerous activity!

Today, rockets are more reliable. They fly on precise courses and are capable of going fast enough to escape the gravitational pull of the Earth. Modern rockets are also more efficient today because we have an understanding of the scientific principles behind rocketry. Our understanding has led us to develop a wide variety of advanced rocket hardware and devise new propellants that can be used for longer trips and more powerful takeoffs.

▸ 3.1 Rocket Motors and their Propellants

Most rockets today operate with either solid or liquid propellants. The word propellant does not mean simply fuel; it means both fuel and oxidizer. The fuel is the chemical the rocket burns; but for burning to take place, an oxidizer (oxygen) must be present. Jet motors draw oxygen into their motors from surrounding air. Rockets do not have the luxury that jet planes have; they must carry oxygen with them into space, where there is no air.

Solid rocket propellants, which are dry to touch, contain both the fuel and oxidizer combined together in the chemical itself. Usually the fuel is a mixture of hydrogen compounds and carbon and the oxidizer is made up of oxygen compounds. Liquid propellants, which are often gases that have been condensed to transform into liquids, are kept in separate containers; one for fuel and the other for oxidizer. Just before firing, the fuel and oxidizer are mixed together in the motor. A solid propellant rocket has the simplest form of motor. It has a nozzle, a case, insulation, propellant and an igniter. The case of the motor is usually a relatively thin material that is lined with insulation to keep the propellant from burning through. The propellant itself is packed inside the insulation layer.

Many solid propellant rocket motors feature a hollow core that runs through the propellant. Rockets that do not have the hollow core must be ignited at the lower end of the propellants and burning proceeds gradually

from one end of the rocket to the other. In all cases, only the surface of the propellant burns. However, to get higher thrust, the hollow core is used. This increases the surface of the propellants available for burning. The propellants burn from inside at a much higher rate, sending mass out the nozzle at a higher rate and speed. This results in greater thrust. Some propellant cores are star shaped to increase the burning surface even more.

To ignite solid propellants, many kinds of igniters can be used. Fire arrows were ignited by fuses, but sometimes they ignited too quickly and burned the rocketeer.

A far safer and more reliable form of ignition used today is one that employs electricity. An electric current, coming through wires from some distance away, heats up a special wire inside the rocket. The wire raises the temperature of the propellant till it reaches combustion point.

Other igniters are more advanced than the hot wire device. Some are encased in a chemical that ignites first, which then ignites the propellants. Still other igniters, especially those for large rockets, are rocket motors themselves. The small motor inside the hollow core blasts a stream of flames and hot gas down from the top of the core and ignites the entire surface area of propellants in a fraction of a second.

The nozzle in a solid propellant motor is an opening at the back of the rocket that permits the hot expanding gases to escape. The narrow part of the nozzle is the throat. Just beyond the throat is the exit cone.

The purpose of the nozzle is to increase the acceleration of the gases as they leave the rocket and thereby maximise the thrust. It does this by cutting down the opening through which the gases can escape. To see how this works, you can experiment with a garden hose that has a spray nozzle attachment. This kind of nozzle does not have an exit cone, but it does not matter in the experiment. The important point about nozzle is that the size of the opening can be varied.

Start with opening at its widest point. Watch how far the water squirts and feels thrust produced by the departing water. Now reduce the diameter of

the opening and again note down the distance the water squirts and feels thrust. Rocket nozzles work in the same way.

As with the inside of rocket case, insulation is needed to protect the nozzle from the hot gases. The usual insulation gradually erodes as the gas passes through. Small pieces of insulation get very hot and break away from the nozzle. As they are blown away, heat is carried away with them.

The other main kind of rocket motor is one that uses liquid propellants, which may be either pumped or fed into motor by pressure. This is a much more complicated motor, as is evidenced by the fact that solid rocket motors were used for at least 700 years before the first successful liquid motor was tested. Liquid propellants have separate storage tanks – one for the fuel and other for the oxidizer. They also have a combustion chamber and a nozzle.

The fuel of liquid propellant rocket is usually kerosene or liquid hydrogen; the oxidizer is usually liquid oxygen. They are combined inside a cavity called combustion chamber. Here the propellants burn and build up high temperatures and pressures and the expanding gases escape through the nozzle at lower end. To get the maximum power from the propellants, they must be mixed as completely as possible. Small injectors (nozzles) on the roof of the chamber spray and mix the propellants at the same time. Because the chamber operates under high pressure, the propellants need to be forced inside. Modern liquid rockets use powerful, light weight turbine pumps to take care of this process.

With any rocket and especially with liquid propellant rockets, weight is an important factor. In general, the heavier the rocket, the more the thrust needed to get it off the ground. Because of the pumps and fuel lines, liquid motors are much heavier than solid motors.

One good method of reducing the weight of liquid motors is to make the exit cone of the nozzle out of very light weight metals. However, the extremely hot, fast-moving gases that pass through the cone would quickly melt thin metal. Therefore, a cooling system is needed. A highly effective, though complex, cooling system that is used with some liquid motors takes advantage of low temperature of liquid hydrogen. Hydrogen

becomes liquid when it is chilled to -235°C. Before injecting the hydrogen into the combustion chamber; it is first circulated through small tubes that lace the walls of the exit cone. In a cutaway view, the exit cone wall looks like the edge of corrugated cardboard. The hydrogen in the tubes absorbs the excess heat entering the cone walls and prevents from melting. It also makes the hydrogen more energetic because of the heat it picks up. This kind of cooling system is known as regenerative cooling.

▶ 3.2 Motor Thrust Control

Controlling the thrust of a motor is very important in launching payloads (cargoes) into orbit. Applying thrust for too short or too long period of time will cause a satellite to be placed in the wrong orbit. This could cause it to go too far into the space to be useful or make the satellite fall back to the Earth. Applying thrust in the wrong direction or at the wrong time will also result in a similar situation.

A computer in the rocket's guidance system determines when the thrust is needed and turns the motor on or off appropriately. Liquid motors do this by simply starting or stopping the flow of propellants into the combustion chamber. On more complicated flights, such as going to the Moon, the motors must be started and stopped several times.

Some liquid propellant motors control the amount of motor thrust by varying the amount of propellant that enters the combustion chamber. Typically the motor thrust varies for controlling the acceleration experienced by astronauts or to limit the aerodynamic forces on a vehicle.

Solid propellant rockets are not as easy to control as liquid rockets. Once started, the propellants burn until they are gone. They are very difficult to stop or slow down part way into the burn. Sometimes fire extinguishers are built into the motor to stop the rocket during flight. But using them is a tricky procedure and does not always work. Some solid fuel motors have hatches on their sides that can be cut loose by remote control to release the chamber pressure and terminate thrust.

The burn rate of solid propellants is carefully planned in advance. The hollow core running the length of the propellants can be made into a star shape. At first, there is a very large surface available for burning, but as the points of the star burn away, the surface area is reduced. For a time, less of the propellant burns and this reduces thrust. The space shuttle uses this technique to reduce vibrations early in its flight into orbit.

CAUTION: Although most rockets used by governments and research organisations are very reliable, there is still great danger associated with fabrication and ignition of rocket motors. Individuals interested in rocketry should never attempt to build their own motors. Even the simplest looking motors are very complex. Case wall bursting strength, propellant packing density, nozzle design and propellant chemistry are all design problems beyond the scope of amateurs. Many home built rocket motors have exploded in the faces of their builders with tragic consequences.

▶ 3.3 Stability and Control System

Building an efficient rocket motor is only part of the problem in producing a successful rocket. The rocket must also be stable in flight. A stable rocket is one that flies in a smooth, uniform direction. An unstable rocket flies along an erratic path, sometimes tumbling or changing direction. Unstable rockets are dangerous because it is not possible to predict where they will go. They may even turn upside down and suddenly head back directly to the launch pad.

Making a stable rocket requires some form of control system. Controls can be either active or passive which will be explained later. All matter regardless of size, mass or shape, has a point inside called the centre of mass (CM). The CM is the exact point where all the mass of the object is perfectly balanced. You can easily find the CM of an object such as a ruler by balancing the object on your finger. If the material used to make the ruler is of uniform thickness and density, the CM should be at the halfway point between the two ends of the ruler. If the ruler were made of wood and a heavy nail were driven into one of its ends, the CM would no longer be in the middle. The balancing point would then be nearer the end with nail.

The CM is very important in rocket flight because it is around this point that an unstable rocket tumbles. As a matter of fact, any object in flight tends to tumble. Throw a stick, and it tumbles end over end. Throw a ball, and it spins in flight. The act of spinning or tumbling is a way of becoming

stabilised in flight. A Frisbee will go where you want it to only if you throw it with a deliberate spin. Try throwing a Frisbee without spinning it. If you succeed, you will see that the Frisbee flies in an erratic path and falls far short of its mark. In flight, spinning or tumbling takes place around one or more of three axes. They are called roll, pitch and yaw. The point where all three of these axes intersect is the centre of mass.

For rocket flight, the pitch and yaw axes are the most important because any movement in either of these two directions can cause the rocket to go off course. The roll axis is the least important because movement along this axis will not affect the flight path. In fact, a rolling motion will help stabilise the rocket in the same way a properly passed football is stabilised by rolling (spinning) it in flight. Although a poorly passed football may still fly to its mark even if it tumbles rather than rolls, a rocket will not. The action-reaction energy of a football passes will be completely expended by the thrower, the moment the ball leaves the hand. With rockets, thrust from the motor is still being produced while the rocket is in flight. Unstable motions about the pitch and yaw axes will cause the rocket to leave the planned course. To prevent this, a control system is needed to prevent or at least minimise unstable motions.

In addition to CM, there is another important centre inside the rocket that affects the flight. This is the Centre of Pressure (CP). The CP exists only when air is flowing past the moving rocket. This flowing air, rubbing and pushing against the outer surface of the rocket, can cause it to begin moving around one of its three axes. Think of a weather vane for a moment. A weather vane is an arrow-like stick that is mounted on a rooftop and used for knowing wind direction. The arrow is attached to a vertical rod that acts as a pivot point. The arrow is balanced so that the CM is right at the pivot point. When the wind blows, the arrow turns and the head of the arrow points into the oncoming wind. The tail of the arrow points in the downwind direction.

The reason that the weather vane arrow points into the wind is that the tail of the arrow has a much larger surface area than the arrowhead. The flowing air imparts a greater force to the tail than the head, and therefore the tail is pushed away. There is a point on the arrow where the surface area is the same on one side as the other. The spot is called the CP. The CP

is not in the same place as the CM. If it were, then neither the end of the arrow would be favoured by the wind nor would the arrow point. The CP is between CM and tail end of the arrow. This means that the tail end has more surface area than the head end. It is extremely important that CP in a rocket be located towards the tail and CM be located towards the nose. If they are in the same place or very near to each other, the rocket will be unstable in its flight.

The rocket will then try to rotate about CM in the pitch and yaw axes, producing a dangerous situation. With the CP located in the right place, the rocket will be stable.

Control systems for the rockets are intended to keep a rocket stable in flight and to steer it. Small rockets usually require only a stabilising control system. Large rockets, such as ones that launch satellites into orbits, require a system that not only stabilises the rocket, but also enable it to change course while in flight. Controls on rockets can be either active or passive. Passive controls are fixed devices that keep rockets stabilised by their very presence on rocket's exterior. Active controls can be moved while the rocket is in flight to stabilise and steer the craft.

An important improvement which came in rocketry was the replacement of sticks by clusters of lightweight fins mounted around the lower end near the nozzle. Fins could be made out of lightweight materials and be streamlined in shape. They gave rockets a dart-like appearance. The large surface area of the fins easily kept the Centre of Pressure behind the Centre of Mass. Some experimenters even bent the lower tips of the fins in a pinwheel fashion to promote rapid spinning in flight. With these spin fins, rockets become much more stable in flight. But this design also produces more drag and limits the rocket's range.

With the start of modern rocketry in 20th century, new ways were sought to improve rocket stability and at the same time reduce overall rocket weight. The answer to this was the development of active controls.

Active control systems include vanes, movable fins, canards, gimballed nozzles, vernier rockets, fuel injection and altitude-control rockets. Tilting fins and canards are quite similar to each other in appearance. The only

real difference between them is their location on the rockets. Canards are mounted on the front end of the rocket while tilting fins are at the rear. In flight, the fins and canards tilt like rudders to deflect the air flow and cause the rocket to change course. Motion sensors on rocket detect unplanned directional changes. Corrections can be made by slight tilting of the fins and canards. The advantage of these two devices is size and weight. They are smaller and lighter and produce less drag than large fins.

Other active control system can eliminate fins and canards altogether. By tilting the angle at which the exhaust gas leaves the rocket motor, course changes can be made in flight. Several techniques can be used for changing exhaust direction. Vanes are small fin-like devices that are placed inside the exhaust of the rocket motor. Tilting the vanes deflects the exhaust and by action-reaction the rocket responds by pointing the opposite way.

Another method for changing the exhaust direction is to gimbal the nozzle. A gimballed nozzle is able to sway while exhaust gases are passing through it. By tilting the motor nozzle in the proper direction, the rocket responds by changing course.Vernier rockets can also be used to change the direction. These are small rockets mounted on the outside of the large motor. When needed they fire, producing the desired course change.

In space, only by spinning the rocket along the roll axis or by using active controls involving the motor exhaust the rocket can be stabilised or have its direction changed. Without air, fins and canards have nothing to work upon. While coasting in space, the most common kind of active control used are altitude-control rockets. Small clusters of motors are mounted all around the vehicle. By firing the right combination of these small rockets, the vehicle can be turned in any direction. As soon as they are aimed properly, the main motor fires, sending the rocket off in the new direction.

▶ 3.4 Mass

Mass is another important factor affecting the performance of the rocket. The mass of a rocket can make the difference between a successful flight and just wallowing around on the launch pad. As a basic principle of rocket flight, it can be said that for a rocket to leave the ground, the motor

must produce a thrust that is greater than the total mass of the vehicle. It is obvious that a rocket with a lot of unnecessary mass will not be as sufficient as one that is trimmed to just the bare essentials.

For an ideal rocket, the total mass of the vehicle should be distributed following this general formula: Of the total mass, 91% should be propellants; 3% should be tanks, motors, fins, etc; and 6% can be the payload. Payloads may be satellites, astronauts or space craft that will travel in the space.

In determining the effectiveness of a rocket design, rocketeers speak in terms of Mass Fraction (MF). The mass of the propellants of the rocket divided by the total mass gives Mass Fraction.

$$\text{Mass Fraction (MF)} = \frac{\text{mass of propellants}}{\text{total mass of the rocket}}$$

The mass fraction of the ideal rocket given as above is 0.91. From the mass fraction formula one might think that an MF of 0.1 is perfect, but then the entire rocket would be nothing more than a lump of propellants that would simply ignite into a fire ball. The larger the MF number, the less payload the rocket can carry; the smaller the MF number, the less its range becomes. An MF number of 0.91 is a good balance between payload-carrying capability and range. The space shuttle has an MF of approximately 0.82. The MF varies between the different orbiters in the space shuttle fleet and with the different payload weights of each mission.

Large rockets, able to carry a spacecraft into space, have various weight problems. To reach space and proper orbital velocities, a great deal of propellant is needed. Therefore the tanks, motors and associated hardware become larger. Up to a point, bigger rockets can carry more payload than smaller rockets, but when they become too large, their structures weigh them down too much and the Mass Fraction is reduced to an impossible number.

A solution to the problem of giant rockets weighing too much can be credited to 16th century fireworks maker John Schmidlap. Schmidlap attached small rockets to the top of big ones. When the large rocket was exhausted, the rocket casing was dropped behind and the remaining

rocket fired. Much higher altitudes were achieved by this method. The rockets used by Schmidlap were called step rockets. Today this technique of building a rocket is called staging.

▶ 3.5 Propellants, Mass and Velocity

Drag is not directly proportional to velocity; doubling the airspeed increases the drag by the square of the velocity. Doubling the speed quadruples the drag forces. Ultimate performance need not be the ultimate goal. But it is vital to understand that loading the biggest motor available, with the greatest mean thrust, is not actually a recipe for the success, either in terms of performance, or reliability. Sound design, which incorporates a slick (smooth) airframe, rigidly made with lightweight material and boosted with correctly chosen propellants, will always win out.

Light weight is better but how much better? Take a golf ball and a similarly-sized ping pong ball, throw them. It is very obvious that the golf ball goes the furthest. The reason is related to the concept of Featherweight Recovery, in which drag forces overpower the weak momentum of very light ball and stop it vertically dead. The question may arise that can this happen to rockets and they be built too light that they slow up quickly in the coast segment? The answer is in the positive but at the same time one has to check its practicality also. RockSim and SpceCad are excellent software to work towards predicting an optimum mass for a given airframe and specific motor.

▶ 3.6 Nose and Fin Shapes

Model rockets are usually made up of cylindrical tube, with a nose cone at the front and fins at the back. The need of the stability is fulfilled by the fins and forward progress of the rocket - ploughing through the air - is accomplished by the nose cone. So, shapes for fins and noses play a crucial role in the entire rocket flight.

Nose Cone

Nose cones can be fabricated in all shapes and sizes. To work with full size rockets is very complex in terms of optimum shape for maximum efficiency and in case of 'big rockets' with payloads, the cargo is always carried in the

nose, which often detracts from optimum aerodynamic design. Smaller sounding rockets are designed for very high velocities - many times the speed of sound - invariably having long, pointed noses. Model rockets fly much slower and the needle point is less efficient than a smooth parabolic curve with a fairly blunt end, like the nose of a passenger airliner. In performance competition, this seems to be borne out by observation, most duration and altitude birds have rounded, rather than pointed noses. However, parabolic or elliptical noses, which are nearly pointed, are very common. But it is very essential to build them perfectly.

An absolute truth is that the nose-body interface must be imperceptible, as roughness or poor fitting creates turbulence. This will make the fins less effective and ensure that the rocket spends more time flying at a significant angle of attack resulting in more drag. Nose shapes can have an effect on rocket stability as speed increases. The phenomenon of laminar airflow becoming turbulent, results in only the outer regions of the fins being effective. Some shapes especially conical noses promote this effect more markedly than others and can mess up the airflow to a point where the fins cannot properly exert restoring forces, resulting in the vehicle going unstable towards the end of the propellant burn. Often much more fin area is the only cure.

Fins

It has been accepted for generations that elliptical fin shapes induce less drag than other shapes and broadly this is true. Fin shapes seem to be less critical than theory suggests. Connected with the fins' Reynolds Number and the fact that the fins are not always called upon to provide restoring forces - and hence not creating lift, which contributes to induced drag. This is a very technical subject, made more so because fins are found at the tail of a rocket, where high speed airflow will have broken up and may be quite turbulent, such that only tips of the fins are flying in relatively undisturbed air.

The cross section of each fin is also a matter for debate. Most authorities state that a symmetrical aerofoil section is the best and ensures that restoring forces are created more effectively. The international contest arena provides little confirmation to this theory, with many successful

fliers choosing thin flat plates as the basis for their fins. The truth lies in the fact that model rockets - especially FAI contest rockets - are relatively small and the fins are tiny compared with the wings of model aeroplanes. The result is that whatever aerofoil section and thickness chosen, works fairly inefficiently. In addition, although aerofoil sections may be more efficient, sanding six identical - in a three fin set up - surfaces introduces a human factor - inaccuracy! Crucially however, fin material must be very rigid - tip flutter is ruinous - and wrap-free fins attached accurately to the rocket's rear body with smooth glue fillets are essential. Here, skill and experience play their role rather than the theory.

▶ 4.1 Components of Solid Propellant Single Stage Model Rocket

Body Tube

The body tube is the basic component of the model rocket. All of the remaining components are either included within or attached to it. It is a cylindrical tube. Dimensions of this tube can affect the performance of the model rocket.

Nose Cone

This is the uppermost part of the rocket. It can be of different types and have different shapes right from conical to semi-spherical. Shape and size of the nose cone can affect the performance of the model rocket. The main function of this part is to help penetrate the model rocket through air smoothly. In other words, nose cone minimizes the effect of air drag on the model rocket while penetrating through air. The nose cone is coupled with the body tube by means of a coupling tube.

Coupling Tube

Coupling tube is a component by means of which nose cone is connected to the body tube. It basically couples nose cone and body tube, so it is known as coupling tube.

Launch Lug

The launch lug is a small, stiff paper tube attached to the rocket. It slides over the rod of the launching pad. It is used to guide the model rocket in the desired direction when it is launched.

Motor

The motor is pushfit in the rear end of the tube. The motor produces thrust which causes the model rocket to boost up. In simple model rocket, we can use the motor of firecracker rockets. But the length of these motors should be proper to create enough thrust in the rockets.

Thrust Ring

This is the motor retaining device. Without this, the motor may come out of the rocket when rocket is launched. It is fixed inside the body tube just

above the motor. It also prevents the motor from moving within the body tube. It serves to transmit the motor's thrust to the body tube.

Structure of Single Stage Model Rocket

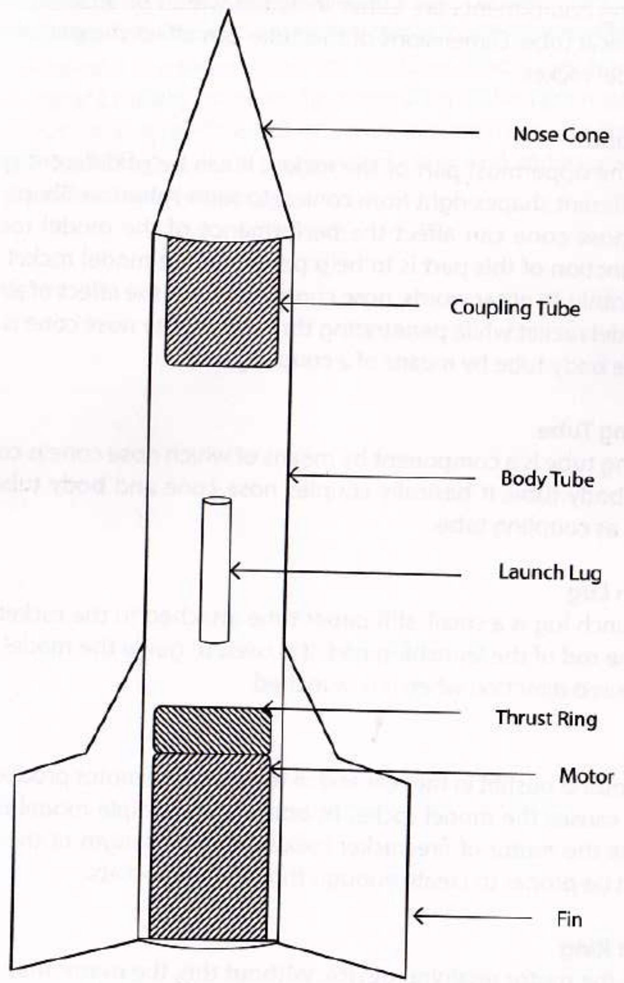

Fig 4.1

Fins

These are attached at the rear end of the body tube. They provide stability during the flight of the model rocket. The size and shape of the fins affect the performance and stability of the model rocket. Fins are attached to the body tube at specific angle e.g. 120° or 90°.

▶ 4.2 Fabrication of Solid Propellant Single Stage Model Rocket

Body Tube

To make the body tube, take a sheet of card paper. Cut a rectangular piece of length 20 cm and breadth 13.5 cm (see Fig 4.2). Now roll this piece around a PVC rod having external diameter of 2 cm. Mark a vertical straight line at first fold. Apply adhesive glue on the other side of the line and roll it again around the PVC rod tightly by matching first fold with the marked line. Stick it properly to have the cylindrical body tube. The adhesive glue should not be applied on the PVC rod. When it is completely dry, remove it from the PVC rod.

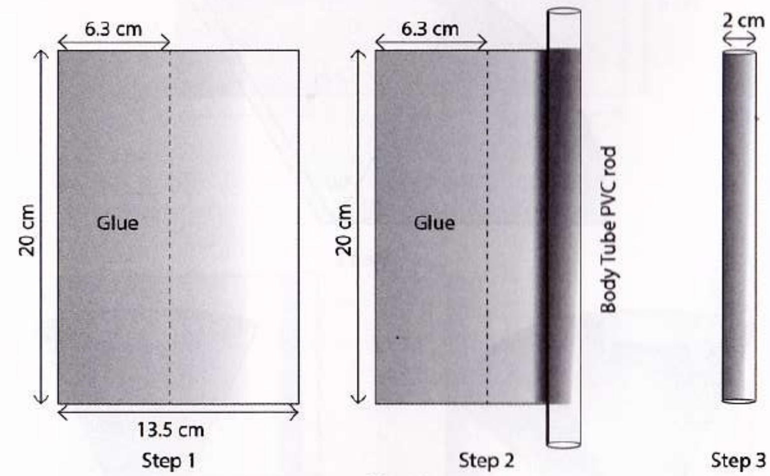

Fig 4.2

Nose Cone

Cut a semicircular piece having diameter 13 cm from the card paper. From the centre of the piece, draw angles of 60° and 120° as shown in Fig 4.3. Draw a parallel line at a distance of 0.5 cm from the right hand side line.

First roll the piece in conical shape. Then cut along the parallel line. Apply adhesive in the right most part and roll the piece to obtain a perfect cone.

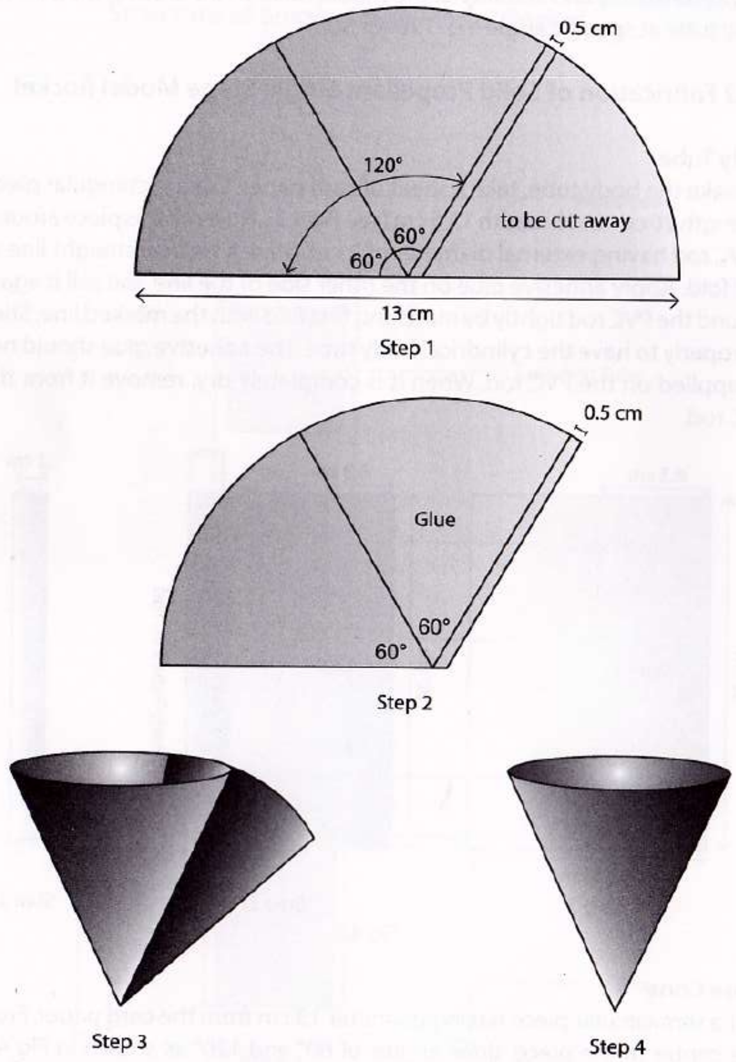

Fig 4.3 Steps of Nose Cone Construction

Coupling Tube

Cut a rectangular piece having dimensions 5 cm x 11 cm from the card paper (see Fig 4.4). Roll it to get cylindrical tube having diameter slightly smaller than the Body Tube and insert it inside the Body Tube. Mark at the edge of the first fold of the Coupling Tube cylinder when it is inside the Body Tube and put 'X' on the opposite end of the mark. Take it out and open it. Draw a straight vertical line at that mark. Apply glue on the portion with the 'X' mark. Start rolling from the other end in such a way that the edge of the first fold exactly matches with the marked straight line. Continue rolling it till you get a cylindrical tube. Take care that the glue has properly dried before moving to next step. Apply the glue on the rim of the coupling tube and stick nose cone onto it.

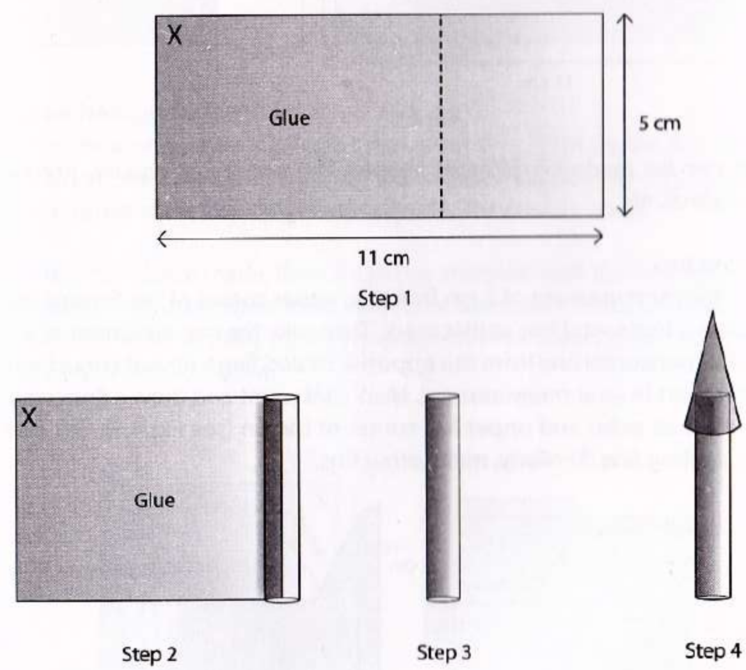

Fig 4.4 Steps of Coupling Tube Construction

Fins

Cut four pieces, each having dimensions 5 cm x 11 cm from the thick card paper (see Fig 4.5). Fold each piece at the midpoint (5.5 cm). Now draw a parallel line at 0.5 cm from both the vertical edges. Fold the ends at these marked lines in opposite directions to get flaps. Stick the two parts with each other. Do not stick flaps with each other.

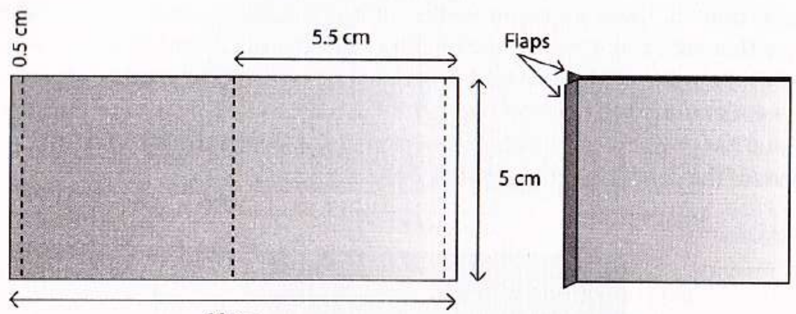

Fig 4.5

Fins can be made of different shapes like triangular, square, irregular hexagonal, etc.

Square fins

Take the measurement of 2 cm from the upper corner of the fin and mark it. Draw a horizontal line at that mark. Then take the measurement of 1 cm on that horizontal line from the opposite folded flaps, do not consider the folded part in your measurement. Mark that point and draw a line joining the marked point and upper left corner of the fin (see Fig 4.6). Cut along this slanting line. Similarly, make other fins.

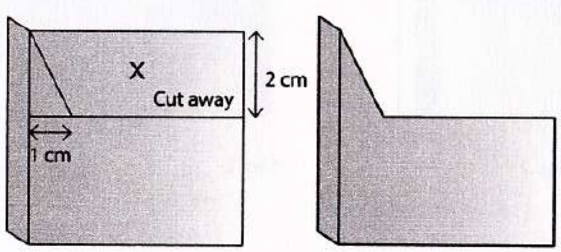

Fig 4.6

Triangular fins

Draw a diagonal and put 'X' mark on the upper triangular portion of the diagonal (see Fig 4.7). Cut along the diagonal and remove the triangular portion marked 'X'. The remaining triangular portion is the triangular fin. Make other triangular fins in similar way.

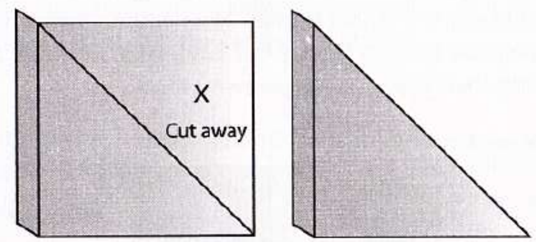

Fig 4.7

Irregular hexagonal fins

Take the measurements of 2 cm on the upper side, 3 cm on the right side and 1 cm on the lower left side from the folded ends (see Fig 4.8). Cut the parts on upper right side and lower left side. The fins are ready.

If four fins have been made, they should be attached with the body tube at an angle 90° between them and if three fins have been made, they should be attached with the body tube at an angle 120° between them. Addition of the angles should be 360°.

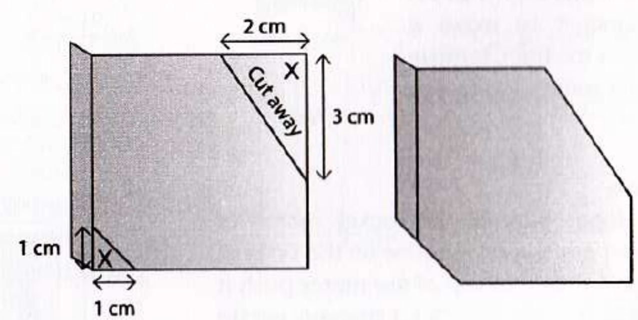

Fig 4.8

Engine (Motor)

Take a firecracker rocket and separate the solid fuel part from it. If it has an ejector bomb part at the top, remove it too. We will be using the solid fuel part after removing the bomb part as the engine (motor) of the model rocket. Scrape off the extra paper sticking on outside of the engine. Now cut a ring of around 1 cm from the top of this engine. This ring will be used as a Thrust Ring for the Model Rocket. After cutting away the thrust ring, if space remains at the top (above the fuel), fill it with tiny paper pieces compactly and then seal it, as per given method.

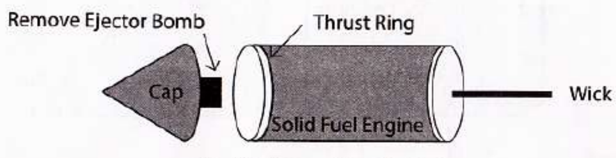

Fig 4.9 Firecracker Rocket

Engine Sealing Disc

To prepare the engine sealing disc cut a circle having 2 cm diameter, from the chart paper. Paste it on the top of the rim of the engine which we have filled with paper pieces, so as to tightly seal it. Now insert this engine inside the body tube. It should fit perfectly. If it remains loose, stick a paper layer around it to make it thicker. If it is too tight, remove (scrape off) some more paper from the engine's side.

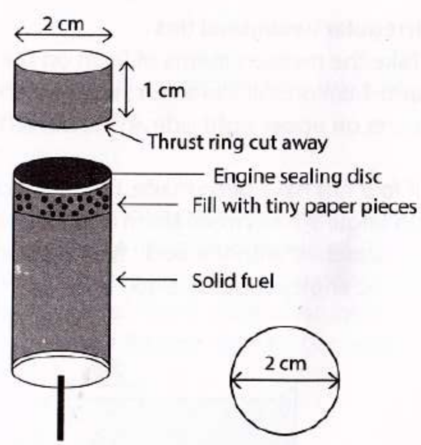

Fig 4.10 Engine Sealing Disc

Thrust Ring

Cut the upper part of the rocket motor of dimension 1 cm. Apply adhesive on the sides of this ring and with the help of the motor push it inside the body tube and stick it properly within the body tube.

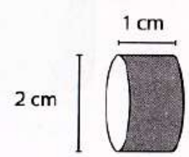

Fig 4.11

Launch Lug

For launch lug, a small piece of straw of proper diameter can be used.(see Fig 4.12) Otherwise use a card paper of dimensions 3 cm x 0.6 cm to roll it on the launch lug rod. Apply adhesive after the first fold and again roll it to stick perfectly. Remove the launch lug rod to obtain the hollow cylindrical launch lug.

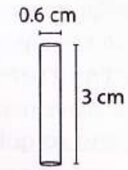

Fig 4.12 Launch Lug

▶ 4.3 Stability of the Rocket: Swing Test

The single stage solid fuel model rocket is ready. But without checking its stability, one cannot launch it. So, the rocket has to undergo the stability test.

This test is performed by swinging the rocket. Take a thread and tie a knot and pass the rocket from that knot. Tight the knot and check the position of the Centre of Gravity of the rocket. The rocket will be balanced at its Centre of Gravity. This means if you hang the rocket by thread at certain height from the ground both the ends of the rocket will remain at equal height from the ground. Point where this balance is achieved is the Centre of Gravity of the rocket.

Now swing this rocket in the air. The stable rocket will stay at 90° with respect to the thread. In whichever direction you rotate the system (clockwise/anti-clockwise), the rocket will remain at 90° with respect to the thread.

If the rocket is not stable plasticine or modelling clay is to be filled inside the nose cone to adjust the Centre of Gravity of the system and to make it stable.

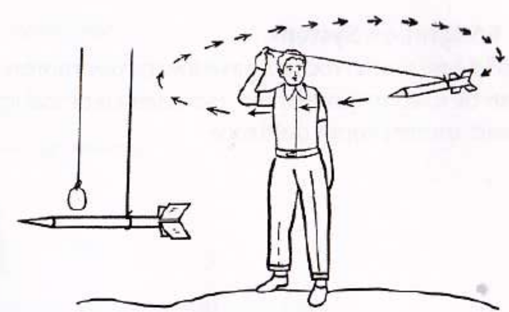

Fig 4.13

▸ 4.4 Launcher

The launcher is an essential tool to have perfect rocket launching. The launcher allows the model to be launched in the desired direction by guiding it before it becomes air borne. Since solid fuel rockets are launched to achieve maximum height, these rockets are always launched vertically up and so guiding rod of launcher is always kept at 90° with respect to ground. This type of launcher can be made easily. (see Fig 4.14)

The Launcher has four main parts as given follows:

A. Base: Base is used to hold rocket launcher straight on the ground. Take a 20 cm x 20 cm x 2.5 cm wooden block and mark its centre. Drill a hole at the centre of the base, so that launching rod can be fitted by pushing it in.

B. Launching rod: Launching rod is used to guide the rocket before it becomes air borne. The rocket is inserted in the launching rod by means of launch lug. Take 1 m long stainless steel rod of 3 mm diameter. Insert this rod through the hole made at centre of the wooden block. Make sure the rod is at 90° with respect to the ground.

C. Jet Deflector: The main function of a jet deflector is to deflect the exhaust from the motor and prevent the platform from getting charred. A jet deflector is a metallic plate of dimensions 18 cm x 4.5 cm, cut out from an aluminium sheet. The jet deflector is fitted at 45° angle from the rod.

D. Collar: The Collar is made up of a thin wire which prevents the model rocket from sliding down to the deflector. For collar, take a thin wire and wind it on the rod around 5 cm above the deflector.

▸ 4.5 Ignition System

Solid fuel model rockets have low power motors, so lighted incense sticks can be used to ignite them. However electrical ignition system can also be used, under proper guidance.

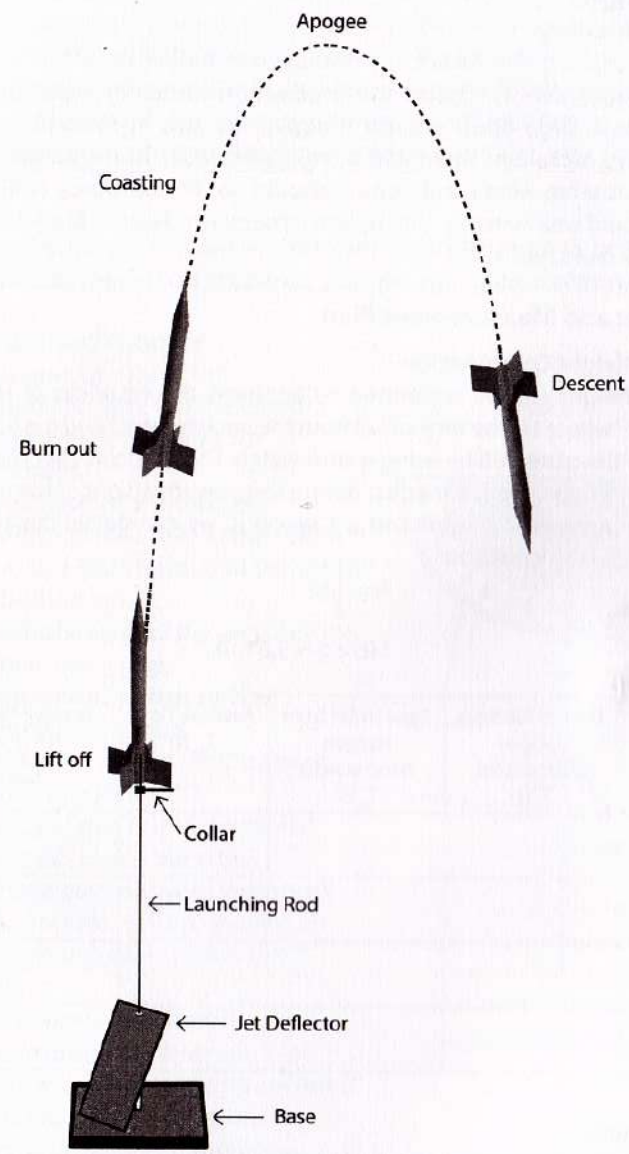

Fig 4.14 Launching of the solid fuel rocket

▸ 4.6 Launching

Before launching the rocket, go through the Model Rocketeer's Safety Codes (Annexure - 1). Collect the necessary material for launching and carry it to a large open ground (roughly the size of football ground) with model rocketeers team and team leader. Move to the centre of the ground. Observe wind conditions. It should not be too windy or else the rocket would weathercock; that is, turn into the wind easily. Model rockets should be launched at 90°.

▸ 4.7 Test and Measurement Plan

Apogee Height Computation

Apogee height can be computed by applying the equation of motion $h = 1/2\,gt^2$ where t is the time of fall from the apogee point and g is $9.8 m/s^2$. The time 't' is observed by using a stop watch. The model rocket rises to a height of 'h' (measured in metres) during the powered flight. If the free fall time from apogee to the ground is 't' seconds, we can derive the altitude by the following equation:

$$h = \frac{1}{2}gt^2$$

Here $g = 9.8\ m/s^2$

Launch No.	Time to fall from apogee (stop watch) T_1 (s)	Time to fall from apogee (stop watch) T_2 (s)	Average Time T_{av} (s)	Apogee height $h = \frac{1}{2}gt^2$ (m)
1				
2				
3				
4				

Inclinometer

The inclinometer is used to measure the maximum altitude the rocket achieves. A clinometer or inclinometer is an instrument used for measuring angles of slope (or tilt), elevation or depression of an object with respect to gravity. It is also known as a tilt meter, tilt indicator, slope alert, slope gauge, gradient meter, gradiometer, level gauge, level meter, declinometer, and pitch & roll indicator. Usually an inclinometer is used to measure the elevation angle of the rocket at peak altitude (apogee). It is a manual process and much depends on the skill of the observer to capture the flying object continuously. Hence, manual errors can vary from person to person.

Material required: Protractor, thick card board (15 cm x 15 cm), scissors, scale (30 cm), thread (15 cm), pencil, push pin, nut, glue, compass (rounder)

Making an Inclinometer

- For preparing base of the inclinometer, take the thick card board having 15 cm x 15 cm dimensions.
- Using the point of a compass (rounder), make a hole at the centre of the card board such that the pencil can be fixed into it.
- Now, fix the edge of the pencil inside this hole using glue.
- Fix the ruler at the base of the protractor using glue.
- Make a small hole at the 0°point at base of protractor.
- Tie a nut at one end of the thread and a push pin on the other.
- Insert the push pin (with the thread) inside the hole in the protractor and fix this arrangement on top of the pencil.
- The inclinometer is ready!
- You can make the observation of angles and calculate height achieved by the model rocket (or different objects), using the inclinometer.

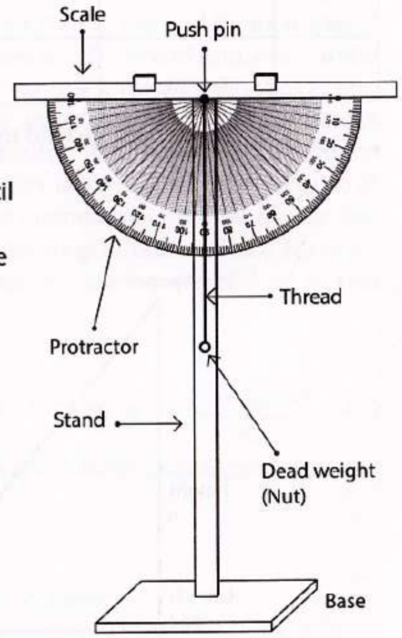

Fig 4.16 Inclinometer

If the distance of the observer at inclinometer from launch pad is 'd' (given in metres) and inclination angle of the apogee point measured is α then the height is given by ***h = d tanα***

Launch No.	Inclinomer angle (α_1)	Inclinomer angle (α_2)	Average angle $\alpha = \frac{\alpha_1 + \alpha_2}{2}$	Apogee height $h = h_1 + d \tan\alpha$ (m)
1				
2				
3				
4				

Height from ground to inclinometer's protractor h_1 = ... m

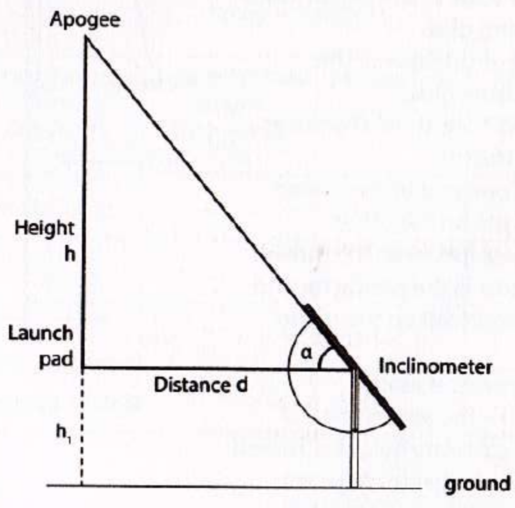

Fig 4.15 Inclinometer

Tracking System

Tracking system is used to track the motion of the rocket after launching. Tracking device measures elevation angle at the point of apogee. Using this data, maximum height achived by the rocket is calculated. Tracking device is made up of wooden ruler and protractor. Tracking device is placed at tracking station, which is far from the launcher. Normally, tracking station should be at a distance equal to the approximate predicted height of the rocket. With the help of tracking device, elevation angle for the apogee is measured.

Model Rocketeers can fabricate their own tracking device. Tracking device is constructed by using a metre scale, protractor and a plumb line. A metre scale attached to a protractor and connected in the middle such that 0° line is aligned with the length of the scale and 90° line of protractor under normal suspension condition. When we track rocket's flight, tracking device should rotate in a vertical plane and plumb line helps to read out different elevation angles on the protractor. The tracking device should be rotated till apogee is achieved. Apogee is the point where rocket is at maximum altitude. At this point, rocket momentarily stops and after that it starts to fall freely under the effect of Earth's gravitational force. For more accuracy, two equidistant tracking stations can be established at two opposite sides of the launcher.

Height Computation

Maximum height achieved by the rocket is given by: $H = \frac{(v_0 \sin\theta)^2}{2g}$ (4.1)

v_0 = Initial velocity, θ = Elevation angle, g = Gravitational acceleration

θ is observed by tracking device, and

$$v_0 = a_y \Delta t$$

where $a_y = -g = -9.8 m/s^2$

Launch No.	Elevation angle (θ°)	Time taken to achieve apogee (Δt) s	Initial velocity (v_0) m/s	Maximum Height (H) m

To calculate V_0

A rocket's motion is like a projectile motion in two dimensions. Its trajectory is always parabola.

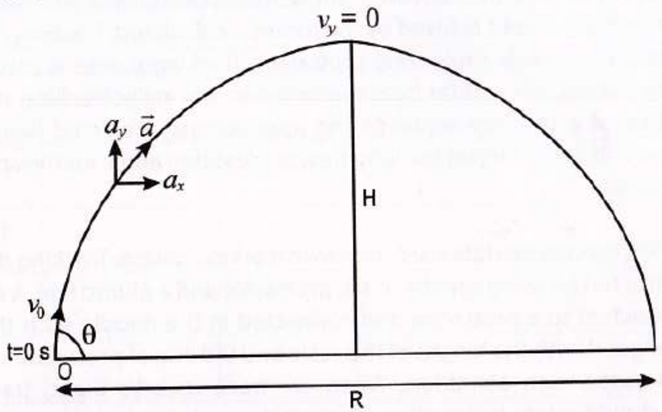

Fig 4.17 Trajectory of a projectile

For a projectile motion,

$$a_x = 0 \quad (4.2)$$

$$a_y = -g = -9.8\ m/s^2$$

$$\text{Now, } ay = \frac{v_{oyf} - v_{oyi}}{\Delta t} \quad (4.3)$$

$v_{oyf} = 0$ at maximum height for momentarily stop condition.

$\Delta t = t_2 - t_1$

Here $t_1 = 0$ and t_2 can be measured by a stop watch. t_2 is the time taken by a rocket to achieve apogee.

By using equation (4.2) in (4.3) we get, v_{oyi} which is the y component of initial velocity. The x component of initial velocity will be 0. Using v_{oyi} and θ in equation (4.1) we get the maximum height achieved by the rocket.

Motion of the rocket after being launched is a Projectile Motion. Projectile motion is always considered in two dimensions during the free fall of the projectile with free fall acceleration g, which is directed downward.

Here we shall consider the rocket as a projectile.

The rocket is launched with some initial velocity v_0, which can be written as

$$v_0 = v_{0x}\hat{i} + v_{0y}\hat{j} \quad (5.1)$$

The components v_{0x} and v_{0y} can be found if we know the angle θ between v_0 and the positive direction of the X-axis

$$v_{0x} = v_0 \cos\theta \quad \text{and} \quad v_{0y} = v_0 \sin\theta \quad (5.2)$$

Duing the two dimensional motion, the rocket accelerates downward, and its position vector $\vec{r}$ and velocity vector $\vec{v}$ change continuously. However, the horizontal motion and the vertical motion are independent of each other except for sharing a common time variable.

▸ 5.1 The Horizontal Motion

Analysis of rocket's motion: Because there is no acceleration in the horizontal direction, the horizontal component of the velocity remains unchanged throughout the motion. The horizontal displacement $x - x_0$ from an initial position x_0 is given by,

$$x - x_0 = (v_0 \cos\theta)\, t \quad (5.3)$$

Here we have taken horizontal component of v_0 and considered $a_x = 0$

▸ 5.2 The Vertical Motion

The vertical motion is the motion for a rocket in free fall. Displacement equation for the rocket can be written as,

$$y - y_0 = (v \sin\theta)\, t - \frac{1}{2}gt^2 \quad (5.4)$$

Here v_0 has been replaced with vertical velocity component. As it is illustrated in Fig 4.17, the vertical velocity component behaves just as for a rocket thrown vertically upward. It is directed upward initially, its magnitude steadily decreasing to zero, which marks the maximum

height of the path. The vertical component then reverses the direction, its magnitude becoming larger and larger as time goes on. Velocity equation can be written as,

$$v_y = v_0 \sin\theta - gt \quad and \quad v_y^2 = (v \sin\theta)^2 - 2g\,(y - y_0) \qquad (5.5)$$

▸ 5.3 Trajectory Equation

The trajectory equation can be found out by eliminating t between the equations (5.3) and (5.4). Solving equation (5.3) for t and substituting into equation (5.4), after a little arrangement, we obtain:

$$y = (tan\theta)x - \left(\frac{g}{2(v_0 cos\theta)^2}\right)x^2 \qquad (5.6)$$

This is the equation of the path shown in Fig 4.17. This equation is of the form $y = ax + bx^2$, in which a and b are constants. This is the equation of a parabola.

▸ 5.4 The Horizontal Range

The horizontal range R of the rocket is the horizontal distance travelled by the rocket when it returns to its initial (launch) height.

To find this, let us put $x - x_0 = R$ and $y - y_0 = 0$

$x - x_0 = (v_0 \cos\theta)\, t = R$

and

$$y - y_0 = (v_0 \sin\theta)\, t - \frac{1}{2} g t^2 = 0 \qquad (5.7)$$

Eliminating t between these two equations yields

$$R = \frac{2v_0^2}{g} \sin\theta \cos\theta \qquad (5.8)$$

But the identity is $\sin 2\theta = 2\sin\theta \cos\theta$ (5.9)

So, we get,

$$R = \frac{v_0^2}{g} \sin 2\theta \qquad (5.10)$$

R has its maximum value when $\sin 2\theta = 1$

This corresponds to

$$2\theta = 90°$$

$$or \quad \theta = 45° \qquad (5.11)$$

▸ 5.5 The Maximum Height

The maximum height achieved by the rocket can be calculated as follows. First we should know the time taken to achieve the maximum height. At maximum height, the rocket is at momentarily static position. i.e. $v_y = 0$

So, we get, $v_0 \sin\theta - g t_m = 0 \Rightarrow t_m = \dfrac{v_0 \sin\theta}{g}$ (5.12)

Substituting the above value in equation (5.4) we get,

$$H = (v\sin\theta)\left(\frac{v_0 \sin\theta}{g}\right) - \frac{1}{2} g\left(\frac{v_0 \sin\theta}{g}\right)^2 \Rightarrow H = \frac{v_0^2 \sin^2\theta}{2g} \qquad (5.13)$$

Time of Flight

Putting L.H.S. of equation (5.4) to be zero, we get,

$$t_f = \frac{2v_0 \sin\theta}{g} \qquad (5.14)$$

▸ 5.6 Effects of Air on the Motion of the Rocket

A fluid is anything that can flow - generally either a gas or a liquid. When there is a relative velocity between a fluid and a body (either because the body moves through the fluid or the fluid moves past the body), the body experiences a drag force D, that opposes the relative motion and points in the direction in which the fluid flows relative to the body.

In rocketry motion or any other kind of projectile motion the relative motion is fast enough to produce turbulence in air fluid behind the body and in such cases the magnitude of the drag force is related to the relative speed v.

i.e. $D = \dfrac{1}{2} C\rho A v^2$ (5.15)

Where, C = Drag coefficient

ρ = the air density

A = Effective cross-sectional area (the area of a cross-section taken perpendicularly to the velocity v)

The above equation indicates that when a blunt object falls from the rest through air, D gradually increases from zero as the speed of the body increases. And if the body falls far enough, D eventually equals to the weight of the body

$W = mg$ and the net vertical force on the body is then zero.

By Newton's second law of motion, the acceleration must also be zero then, and so the body's speed no longer increases. The body then falls at a constant terminal speed v_t, which we find by setting $D = mg$. Then we get,

$$mg = \frac{1}{2} C\rho A v_t^2$$

$$\Rightarrow vt = \sqrt{\frac{2mg}{C\rho A}} \tag{5.16}$$

Variable Mass Problem

Rocket's motion is governed by Newton's third law of motion. However, here we are dealing with variable mass condition rather than a constant mass condition. In rocket's flight, gases are produced by the combustion of fuel stream out with great speed, giving thrust to the rocket in opposite direction. And here, if the rocket is identified as the 'system', the mass of the system is obviously not constant; it decreases continuously with time. For such systems, let us again concentrate on Newton's laws of motion.

Newton's 2nd law can be re-written as,

$$Fext\ \Delta t = \Delta P \tag{5.17}$$

where F_{ext} = total external force at time t

ΔP = change in momentum from time t to $t + \Delta t$ and $\Delta t \to 0$

Consider a rocket that is continuously losing its mass due to the ejection of combustion of gases.

Let $m(t)$ be its mass at time t. At $t + \Delta t$, the mass of the rocket is $m(t) - |\Delta m|$ where, $|\Delta m|$ is mass of gases ejected out in Δt. The appropriate fixed mass system for interval t to $t + \Delta t$ is the rocket of mass $(m - |\Delta m|)$ and the fuel of mass $|\Delta m|$. At t, the fuel is inside the rocket and at $t + \Delta t$ the burnt fuel is outside the rocket.

Let $v(t)$ be the velocity of the rocket at t (relative to a laboratory observer) and $v(t) + \Delta v(t)$ its velocity at $t + \Delta t$. Let v be the speed of the ejected gases relative to the same observer. The initial momentum of the fixed mass system at t is mv and the final momentum of the same system is $(m - |\Delta m|)(v + \Delta v) - |\Delta m|(v')$, where the negative sign arises because the ejected gases come out in the opposite direction of motion of the rocket. The speed characteristic of the fuel burning mechanism in the rocket is the speed of ejected gases relative to the rocket. Denote it by v_r. Obviously $v' = v_r - v$

If the rocket is out in the space without any external force such as gravity, the momentum of the fixed mass system should remain unchanged.

$$(m - |\Delta m|)(v + \Delta v) - |\Delta m|(v_r - v) = mv \tag{5.18}$$

Neglecting the small term $|\Delta m|\Delta v$ in comparison to the other terms we get,

$$m\Delta v - |\Delta m|\, v_r = 0 \tag{5.19}$$

If dm is change in mass in the vanishingly small time interval dt, $|\Delta m| = -dm$. This gives,

$$m\frac{dv}{dt} = -\frac{dm}{dt} v_r \tag{5.20}$$

This equation can be easily interpreted. At any instant t, the acceleration $\frac{dv}{dt}$ of the rocket arises due to the external force gases.

$\frac{dm}{dt} v$ provided by the ejecting gases.

Here $\frac{dm}{dt}$ is negative, so the sign of force is positive,

giving a forward acceleration to the rocket. v_r , characteristic of fuel burning mechanism in the rocket may be taken as an invariable quantity. Further if the ejection rate $\frac{dm}{dt}$ is constant, the force on the rocket due to the ejecting gases is constant.

But since m is a variable and decreases with time, the acceleration of the rocket is also not constant and goes on increasing with time. Equation (5.20) can easily be integrated to give v as a function of time.

$$mdv = -dmv_r$$

Integrating on both the sides we get,

$$\int_{v_0}^{v} dv = -v_r \int_{m_0}^{m} \frac{dm}{m}$$

$$\Rightarrow v - v_0 = -v_r \ln \frac{m}{m_0}$$

$$\Rightarrow v = v_0 + v_r \ln \frac{m}{m_0} \quad (5.21)$$

Where m_0 and v_0 are the initial mass and velocity of the rocket respectively. If the fuel consumption has a rate α, then equation (5.21) can be written as,

$$v = v_0 + v_r \ln \frac{m_0}{m_0 - \alpha t} \quad (5.22)$$

Thrust (T) on the rocket is defined as,

$$T = \alpha v_r \quad (5.23)$$

These equations enable us to take into account the effort of the variation in the mass of rocket during flight.

ANNEXURE - 1

MODEL ROCKETEER'S SAFETY CODE

Dos	Don'ts
1. For construction of model rocket, use light weight material e.g. paper, wood, plastic, rubber, etc.	1. Do not use metal in construction part, otherwise the model may act as a weapon. The model should not exceed 500 gm in weight.
2. Test stability of the model rocket before launching it. Fly only stable rockets.	2. Do not launch unstable rockets.
3. Fly the model in open area free from people and public property.	3. Do not fly in high wind, near buildings, power lines, tall trees, etc. Never attempt to recover the rocket from a power line or other dangerous places.
4. Launch a model rocket from a launcher.	4. Never launch rocket without a launcher.
5. Keep the tracker along the eye level.	5. Never place your head or body over the launch pad.
6. Keep the launching device vertical.	6. Never project rockets horizontally or inclined as it can cause accidents.

ANNEXURE - 2

ON THE FIELD

After completion of fabrication of different designed rockets, they are launched by using a launcher in an open ground.

After selecting proper ground for launching, prepare rocket for launching. To avoid confusion and to take symmetric observations, we need to form teams for specific tasks. Each team may consist of 3-4 members with a team leader.

Tasks of the teams

A. Launching Team: The leader of the launching team has several important tasks to do. He/She with team members keeps the launching area clear. Within 50 m of the launching pad, nobody should be present. He/She also takes care that there are no inflammable materials in the vicinity of the launching pad. When he/she is sure that the tracking team, height computing team and recording team are ready, he/she gives a "GO" signal to the teams. He/She also begins countdown.

B. Tracking Team: Tracking team consists of four persons. Two members of the team track from station 1 and other two from station 2. Both these stations are equidistant from the launcher. At each station, one of them tracks the rocket, while the other one reads the angle. When they are ready, they report "TRACKING GO" to the leader of launching team. They track the rocket till the apogee is achieved. They note down the angle of elevation and report the same to the height computing team.

C. Time Measuring Team: This team consists of two members. Each member measures time taken by the rocket to achieve apogee with the help of the stop watches. They should start their measurement just after the rocket is fired & average time of both the members should be considered for further calculation to maintain more accuracy.

D. Height Computing Team: Height computing team consists of two members. When they receive the data from tracking team, they calculate height using the equations. When they are ready with the result, they give "COMPUTING GO" signal to the leader of launching team.

E. Recording Team: Recording team members record performance of the model rocket. They record information such as elevation angle reported by both the tracking stations, time taken by the rocket to achieve apogee, initial velocity of the model rocket and height achieved by the rocket as reported by the height computing team. When recording team members are ready they give "RECORDING GO" signal to the leader of launching team.

The Countdown

When all teams are ready, the launching team leader gives an "ALL ALERT" signal and starts the countdown. "Ten, nine, eight, ……, two, one, FIRE!" And the rocket is fired. The countdown is necessary as it makes people alert and cautious before launching.

Follow up Activities

After the flights are over, the whole group can participate in discussion regarding the performance of the individual rockets. The instructor should coordinate the discussion so that the possible defects of the models can be brought out. The students can then apply from what they have learnt to construct a rocket to give best performance.

One can build several identical rockets, launch and track them on the same day and study the performance. This type of experiment would give an idea regarding the normal uncertainty or variation from flight to flight as the performance of the rocket may vary even if the designs are identical.

Remember that an activity like Model Rocketry not only generates an interest in science, but also trains the children to approach a problem in a scientific way. Besides, they learn to work in a group where a good deal of co-operation, coordination and discipline are required. These are some of the activities that lie at the heart of all scientific endeavours.

References

LODGE, Stuart
The Model Rocketry Handbook 21st Century Edition
Publisher: Special Interest Model Books
ISBN: 1-85486-229-4

VAN MILLIGAN, Timothy S.
Model Rocket Design and Construction 2nd Edition
Publisher: Kalmbach Books
ISBN: 096536201-9

VAN MILLIGAN, Timothy S.
Model Rocket Design and Construction 3rd Edition
Publisher: Kalmbach Books
ISBN: 13:978-0-9653620-2-3

Rockets- A Teachers Guide with Activities in Science, Mathematics and Technology
Publisher: National Aeronautics and Space Administration

Notes